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Conditions of Rangelands before 1905

ABSTRACT

Paleoecological sources indicate that the location and extent of Sierra Nevada rangelands have varied significantly during the last 20,000 years. Modern vegetative associations are recent, with montane wet meadows appearing during the last 3,000 years. A late Pleistocene sagebrush grassland existed where montane and subalpine forests occur today. In the central Sierra a pattern of deglaciation and vegetative response was repeated at different times depending on location, from alpine grassland to a diverse mixture of conifer and shrub species in an open forest structure. The Holocene began with a decline in mesic species and increased charcoal and oak pollen, indicating a warming trend. A cooler, wetter climate followed as mesic conifers reappeared and evidence of fire decreased.

Historical accounts indicate that highly productive rangelands existed when Europeans arrived. Large ungulate populations were present, and perennial grasses dominated foothill rangelands. Numerous observers reported severe overgrazing by livestock in the late 1800s, due in part to a lack of regulation of the common rangelands. Livestock management contributed to annual grassland conversion on the west side and to juniper woodland expansion on the east side of the range.

The abundance of a diverse assemblage of large grazing mammals at the end of the Pleistocene indicates that Sierra Nevada rangelands were highly adapted to intense grazing pressure and that animal disturbance was an integral part of this highly productive system. This evidence argues for a recognition that well-managed animal disturbance is as vital as well-managed fire to ecosystem health and sustainability.

INTRODUCTION

An assessment of the health of Sierra Nevada ecosystems requires some basis from which to evaluate current conditions. That is, how similar are current ecosystems to those of the past, and to what extent do recent historical conditions represent their range of variability over longer periods of time? The purpose of this chapter is to address the second of the three basic assessment questions; that is, what were the conditions of Sierra Nevada rangeland ecosystems in the past, and how have these ecosystems varied over recent geologic and historic time intervals? Here, rangelands are defined broadly to include the grassland-, woodland-, and chaparral-dominated associations that have been used by livestock and wild ungulates within the study area in the past. A more precise definition of current Sierra Nevada rangeland ecosystems can be found in Menke et al. 1996.

This chapter reviews available historical and paleoecological information on past conditions and the natural range of variability of rangeland resources within the project study area, from the late Pleistocene to the start of public ownership at the turn of the century. The focus here is on the last 20,000 years, a period encompassing a wide range of climatic and ecological conditions, from near-maximum glacial advance, through a period of deglaciation, to more recent intervals that were evidently hotter and drier than the current climate. The first part of the chapter looks at paleoecological studies that illuminate century- and millennial-scale changes in rangeland vegetation. The second part of the chapter addresses questions concerning the conditions and use of Sierra Nevada rangelands during the initial European exploration and settlement period from 1579 to 1905, when public ownership of these lands was consolidated. The final part of

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the chapter discusses implications of these findings for the management of Sierran rangelands. Questions relating to the use and management of these rangelands since 1905, and to their current condition and trend, are addressed in Menke et al. 1996.

Organization of the chapter is basically chronological. Following the review of paleoecological conditions is a review of historical rangeland conditions and uses. The historical review focuses primarily on foothill and montane rangelands, based on the limited coverage of early accounts. These accounts cover the period from initial European exploration and settlement to the consolidation of public ownership in 1905, with special emphasis on the period from 1860 to 1900 when rangeland resources were heavily affected by Europeans. Sources of data include accounts by explorers, trappers, settlers, naturalists, and surveyors. Although some readers may find the historical accounts "subjective," they are the best available sources of information on rangeland condition during the settlement period.

Data used by paleoecologists to reconstruct past environments of the Sierra Nevada include tree-ring chronologies; lake and meadow sediment stratigraphy and fossil content; existing and prehistoric lake levels and glacial extents; and pack-rat midden pollen and macrofossils. These proxy data, taken together, sketch an outline of Sierra Nevada rangeland ecosystems and how they have responded to climatic variability.

Unfortunately, data relating to past rangeland conditions are limited, both for the distant past and for the period of European settlement. These limitations are due in part to the lack of systematic studies of rangeland conditions during the settlement period (Burcham 1957). In addition, current paleoecological research of the Sierra Nevada suffers from limited spatial and temporal resolution. Finally, it is often difficult to interpret paleoecological data because of a diversity of ecosystem responses to changing environmental conditions. However, these sources do provide a picture of the location, general composition, and extent of broad rangeland types, and the relative productivity of past Sierra Nevada rangeland ecosystems.

In addition to assessing the health of current rangeland ecosystems and reviewing past conditions, initial rangeland research objectives included a review of evidence for a late Pleistocene megafaunal herbivory and its coevolution with rangeland vegetation; a review of adaptive livestock-management strategies that recognize these plant-herbivore relationships; evidence of successful application of these strategies by practicing land managers; and implications of this evidence for management of Sierra Nevada rangelands. After initial review of the literature in these areas, it became clear that this chapter could not adequately address all these objectives.

Considerable scientific controversy has arisen among ecologists over whether herbivory can benefit plant communities, in part because such benefits challenge established paradigms about the role of animal disturbance in wildland ecosystems. A large body of reductionist research aimed at selected rangeland ecosystem processes has expanded our knowledge of plant-herbivore relationships but generally fails to address the full complexity of ecosystem response. In many cases, there has been a confusion over benefits to individual plants or communities versus benefits to the overall ecosystem. Key findings from these studies are presented later.

It is clear, however, that plant-herbivore interactions are very site- and time-specific and that achieving potential benefits depends on adapting rangeland management to these specific conditions. Even a complete review of this literature would not answer questions that can be addressed only through adaptive experimental designs. Given a lack of adaptive rangeland-management studies in the project area, project resources were allocated to analyzing current data on rangeland condition and trend, as addressed in Menke et al. 1996, rather than further exploring these broader questions.

LATE PLEISTOCENE PALEOECOLOGY OF THE SIERRA NEVADA

Geologists define the Quaternary period as the most recent, covering the last two million years or so of geologic time. This period is divided into the Pleistocene and the Holocene epochs, at between 12,000 and 10,000 B.P. As noted earlier, paleoecologists analyze a variety of data to infer past ecological and environmental conditions about a given site or region.

Recent investigations of paleoenvironmental conditions continue to modify the picture generated by earlier research and to call into question past theories about climate change, ecological succession and climax, and the delineation of existing plant community types. This is because it is often difficult to find modern analogs to some of the plant associations that evidently existed within the study area in the past (Davis and Moratto 1988; Grayson 1993). In addition, it appears that the Sierra Nevada has had a different climatic history than the Great Basin during the last 12,000 years (Davis and Moratto 1988).

Western-Slope Montane Vegetation

Cole (1983) analyzed one modern and six Pleistocene packrat middens from caves in lower Kings Canyon ranging in elevation from 920 to 1,270 meters (~3,000–4,000 ft). This area is within the present oak-chaparral woodland vegetative zone in California. The modern midden showed a high correlation with local vegetation, as determined by three 60 m (197 ft) transects within 100 m (328 ft) of the midden. The Pleistocene middens ranged in age, with five of the six falling between 20,000 and 12,500 B.P. The middens were analyzed for both pollen and plant macrofossils. Results showed that the vegetation in this zone was completely different from the present vegetation, with no evidence of the modern oak-chaparral community. Instead, the assemblages included a high abundance of Pinus and Artemisia pollens as well as macrofossils indicating a mixed coniferous forest dominated by the xerophytic conifers western juniper, ponderosa pine, sugar pine, and single-needle piñon. This mixture is similar to that found on the east side of the Sierra crest today, but 500 to 1,000 m (1,641 to 3,281 ft) higher in elevation than the Kings Canyon middens.

This assemblage seems to indicate a Pleistocene climate considerably drier than today at this site. Also present, however, are macrofossils of mesophytic taxa California nutmeg, incense cedar, and red fir, as well as a few pollen grains of giant sequoia. Although presence of these latter taxa suggests precipitation levels higher than exist today on the east side of the range, Cole (1983) felt that the presence of the xerophytic conifers indicated current east-side levels of precipitation, but with a colder climate, causing a greater proportion of moisture to fall as snow. A cooler climate would lower evapotranspiration losses and allow for more mesic microclimates in snow-filled depressions. The youngest sample (~12,500 B.P.) did not contain any fossils of the mesophytic taxa, indicating a trend to a drier climate toward the end of the Pleistocene.

Additional sources of information are pollen and plant macrofossils within and stratigraphy of montane meadow sediments. Meadow sediments have been analyzed from sediment cores (Anderson 1990; Anderson and Smith 1994; Davis and Moratto 1988; Smith and Anderson 1992) and from meadow gullies (Wood 1979).

Smith and Anderson (1992) examined a sediment core from Swamp Lake, at 1,554 m (~5,100 ft) in Yosemite National Park, that provides a record of environmental change during the last 16,000 years, based on pollen, macrofossil, and charcoal analyses. The core stratigraphy indicates Tioga-stage deglaciation between 16,000 and 13,700 B.P. During this interval, the fossil record indicates that herbs and sagebrush dominated the Swamp Lake environment, suggesting a cooler and drier climate than at present, similar to the conditions today 1,000 m (3,281 ft) higher and east of the Sierra crest.

By 12,000 B.P., pollen and macrofossil data indicate that subalpine, lower and upper montane conifers became established around the edge of Swamp Lake. These included lodgepole pine, sugar and ponderosa pine, red and white fir, mountain hemlock, incense cedar, and Sierra juniper (Juniperus occidentalis). Sagebrush and herbaceous pollen percentages decline throughout the interval from 13,700 to 10,400 B.P., while charcoal concentrations increase. This anomalous mix of high-elevation and lower montane conifers about 12,000 B.P. suggests a climate that was not just cooler and wetter, but fundamentally different from current conditions. Smith and Anderson (1992) offer several possible causes for this anomaly, including a greater seasonality than at present, with perhaps cooler, wetter winters and warmer summers. Alternatively, a lag in vegetation response to climatic change may have allowed subalpine and upper montane species to persist in favorable microhabitats. These conditions from 12,000 to 10,000 B.P. in Yosemite are consistent with the evidence from the middens in lower Kings Canyon dated earlier than 14,000 B.P., at elevations from 920 to 1,270 m (~3,000–4,000 ft).

Davis and Moratto (1988) analyzed macrofossil and pollen samples from cores of Exchequer Meadow, at an elevation of 2,219 m (7,280 ft) in the Sierra National Forest. The base of the core was radiocarbon dated to 13,500 B.P. and was divided into three zones based on predominant vegetation in the samples. The basal Artemisia zone (13,500–7070 B.P.) suggests vegetation and a climate that is drier than today's on the west side of the range. It also contains giant sequoia pollen, indicating a late Pleistocene climate with temperature ranges similar to those of today.

The Artemisia zone was further subdivided into upper Quercus and lower Gramineae subzones at 10,680 B.P. The inferred vegetation in the lower subzone was an alpine grassland. High levels of spores of the dung fungus Sporormiella in the Gramineae subzone indicate that grazing animals were abundant during this period. These spores are present in sediments older than 11,000 B.P. in several sites in the western United States (Davis 1987) and are linked directly to extinct megafauna by their presence in fossil mammoth dung (Davis et al. 1984; Mead et al. 1986). Absence of these spores after 11,600 B.P. here may date the extinction of Rancholabrean herbivores at middle elevations in the western Sierra. Transition to the oak subzone indicates a rapid climatic warming about 11,000 B.P.

Anderson (1990) analyzed pollen and plant macrofossils from sediments in three high-elevation lakes in the Sierra, including Tioga Pass Pond at 3,018 m (9,900 ft) on the crest, Barrett Lake at 2,816 m (9,239 ft) on the east slope, and nearby Starkweather Pond at 2,438 m (8,000 ft) on the west slope, the latter two near Mammoth Lakes. His analysis indicates that deglaciation occurred later, after about 12,000 B.P. at these higher elevations, than at the middle-elevation sites cited earlier. During the remaining interval of the Pleistocene (to 10,000 B.P.), the lack of macrofossils indicates that trees were absent or poorly established at Barrett Lake and Starkweather Pond. Pollen suggests the nearby vegetation probably included pine, juniper, sagebrush, and grasses. Sediments at Tioga Pass Pond do not predate the end of the Pleistocene.

Great Basin Vegetation in the Late Pleistocene

Analysis of the paleoenvironment of the Great Basin indicates that it was considerably cooler and wetter during the late Pleistocene than at any subsequent time (Grayson 1993). The strongest indicators of this climatic condition are the levels of Great Basin lakes during this interval. Lake Lahontan at its maximum, about 14,000 B.P., covered about fourteen times more surface area than its modern remnants and extended well into California near present-day Honey Lake on the Susan River. Benson et al. (1990) show that Lake Lahontan, Lake Russell (prehistoric Mono Lake), and Lake Searles in the Owens Valley all achieved high stands between 15,000 and 13,500 B.P.

Wigand and Mehringer (1985) analyzed pollen and seeds from Hidden Cave near Carson Sink and concluded that a sagebrush steppe existed there in the late Pleistocene. Subalpine conifers occupied very low elevations at that time, with an understory of sagebrush, winterfat, and shadscale (Grayson 1993; Wigand et al. 1995).

Koehler and Anderson (1994) examined pack-rat middens 10 m (33 ft) above the highest level of Pleistocene Lake Owens, dated from about 23,000 to 14,500 B.P., to infer lakeshore vegetation during this interval. Their data suggest a woodland consisting of Utah juniper and single-needle piñon, green ephedra, wild rose, and Menodora, with Rocky Mountain juniper, which does not occur today in California, present to about 16,000 B.P. Pollen analysis indicates a xeric upland desert-scrub association nearby, with the more mesic conditions at lakeshore due to higher ground-water levels. Jennings and Elliott-Fisk (1993) analyzed middens from the White Mountains that show juniper woodlands extending 600 m (1,968 ft) lower in elevation in the late Pleistocene than at present.

Grayson (1993) argues that a great deal of evidence indicates a cool, moist climate in the late Pleistocene; such evidence includes inferred vegetation, lake levels, and human population levels and dietary patterns. As in the Sierra, plant associations with no modern analog appear in the basin during this period. Problems exist with current concepts of habitat type and condition and trend, which do not reflect recent evidence about dynamic vegetative response to disturbance and climatic change (Grayson 1993; Tausch et al. 1993). That is, the concept of "potential natural condition" of rangeland sites, resulting from successional processes in the absence of disturbance, needs review (see also Woolfenden 1996).

Late Pleistocene Herbivory

One issue in the debate about western rangeland management is the role of Pleistocene megafauna in the evolution of rangeland ecosystems. As noted earlier, initial research objectives were to review evidence for the existence of these animals in the study area and the role of large animal disturbance in rangeland ecosystems. This section reviews pertinent literature on these questions, within the limits mentioned in the Introduction.

Wagner (1989) lists twenty species of late Pleistocene grazing mammals that existed in California as late as 11,000 B.P. This list includes two or more species of horse, tapir, llama, camel, pronghorn, and bison, as well as mammoth, mastodon, shrub ox, musk ox, and the other surviving large herbivores, mule deer, elk, and bighorn sheep. Given the diversity of both herbivorous species and their likely predators, Wagner concludes that California grasslands would have sustained heavy grazing pressure, equal to or greater than what occurs in contemporary East African savannas (Wagner 1989). Edwards (1992) discusses the inferred dietary preferences of the large herbivores present in California during the late Pleistocene and their probable impact on native perennial bunchgrasses. He concludes that the native grasses would have been heavily grazed and trampled and that their ability to benefit from this kind of disturbance is still present. Edwards (1992) also compares the diversity of the California Pleistocene megafauna to that in East Africa today.

The Great Basin also had a large and diverse Pleistocene megafauna. Grayson (1993) identifies some twenty-four sites containing species of extinct Pleistocene mammals that are within or near the Sierra Nevada Ecosystem Project (SNEP) study area (see Grayson's Table 7.2). These large mammals included three species of ground sloth, giant short-faced bear, saber-toothed cat, American lion, American cheetah, several species of horse, flat-headed peccary, camel, llama, shrub ox, musk ox, mastodon, and mammoth. The diversity of large predators in this group would have caused wild herbivore behavior to differ radically from conventionally managed rangeland livestock in the western states.

Taken together, the paleontological evidence indicates that a diverse assemblage of large mammals occupied the Sierra Nevada region in the Pleistocene. As discussed earlier, the dung fungus Sporormiella is abundant in sediment cores of Sierra Nevada meadows before 11,000 B.P., indicating that grazing animals were abundant in the Sierra Nevada until sometime near the end of the Pleistocene (Davis and Moratto 1988). The implied diversity and abundance of this assemblage indicate that Sierra Nevada rangelands were highly adapted to grazing by large herds of wild herbivores and that this kind of severe disturbance was an integral feature of these ecosystems.

Several authors (Edwards 1992; McNaughton 1979; Savory 1988) have argued that there are in fact beneficial impacts of animal disturbance on rangeland plant communities. McNaughton (1976) showed that net primary productivity of East African rangelands was increased by the impacts of large migratory herds grazing at different times in the same areas. McNaughton (1979) later identified ten pathways through which plants benefit from grazing. These include greater photosynthetic activity from removal of senescent plant material, increased conservation of soil moisture by greater water-use efficiency, and increased nutrient recycling from dung and urine. Savory (1988) argues that many researchers ignore the role that large ungulates play in providing favorable conditions for seedling establishment through the combined effects of soil disturbance, compaction, and fertilization.

Savory (1988) developed an adaptive resource-management process that recognizes these beneficial plant-herbivore interactions. He maintains that grazing animals, when managed to mimic wild herds under predator pressure, are necessary to maintain healthy rangelands under many conditions. This model also recognizes that rangelands need to be managed as complete systems and that management must be adaptive to realize beneficial effects and avoid adverse impacts. Although many ranchers using this adaptive approach have had notable success in improving the health of their rangelands, controlled experiments on fixed rotational grazing systems have failed to duplicate these results, pointing out the difficulties in designing and conducting truly adaptive research. Similar criticisms by proponents of adaptive management have called for experimental designs that allow more flexibility and address the full complexity of ecosystem responses (Walters and Holling 1990). For additional discussions of adaptive ecosystem management, see Kusel et al. 1996.

This view of plant-herbivore relationships, which contradicts conventional wisdom about the detrimental impacts of overgrazing, has spawned a vigorous debate over the role of grazing in rangeland ecosystems (Edwards 1992; McNaughton 1979, 1983, 1986, 1993; Oesterheld and McNaughton 1991; Oesterheld et al. 1992; Savory 1988). As discussed in the Introduction, a lack of studies that faithfully duplicate the adaptive livestock-management process precluded a more thorough examination of this debate.

Nevertheless, the paleoecological record supports the view that a highly productive rangeland ecosystem existed in the project study area during the last 20,000 years and that this rangeland vegetation supported a large and diverse megafaunal assemblage before mass extinctions about 10,000 years ago. The implications of this conclusion for management of Sierra Nevada rangelands are discussed in the last section of this chapter.

CHANGING HOLOCENE PALEOENVIRONMENTS

Geologists divide the Quaternary period into Pleistocene and Holocene epochs, with the dividing date set between 12,000 and 10,000 B.P. (Grayson 1993; Wigand et al. 1995). Grayson (1993) notes that ecological changes at this time were often transitional and that the timing of these changes varies with location. It also appears that the timing inferred for these changes depends on the kind of evidence used. Changes in vegetation on the western slope of the Sierra in the late Pleistocene indicated a trend toward warmer and drier conditions than today's. The Great Basin, on the other hand, while drier than at glacial maximums, showed higher lake levels than exist today. However, the vegetative changes beginning there about 12,000 B.P. indicate a warming trend (Wigand et al. 1995).

In the Great Basin, this major change to hot and dry conditions becomes most evident by about 8000 to 7500 B.P. (Grayson 1993). In the Sierra, a shift seems to have occurred toward cooler and wetter conditions about 6500 B.P., depending on elevation and latitude, followed by another shift at about 3700 B.P., to the even cooler, wetter Neoglacial regime. A change is also observed in the Great Basin about 4500 B.P., toward a cooler, wetter climate. This late Holocene Neoglacial interval, ending about 2000 B.P., is indicated by expansion of woodlands and a grassy sagebrush steppe in the Great Basin and by wet meadow formation in middle elevations of the Sierra (Wood 1979).

Sierra Nevada Holocene Environment

Smith and Anderson (1992) argue that an early Holocene xeric period in the Sierra began about the end of the Pleistocene, based on pollen, macrofossil, and microscopic charcoal analysis of sediments from Swamp Lake. This interval of warm, dry climate showed high oak and minimum fir pollen percentages and maximum charcoal concentrations for this site. This xeric period lasted until about 6500 B.P., when fir pollen increased and charcoal concentrations decreased, suggesting a cooler and/or wetter trend.

The zone from 10,400 to 6500 B.P. shows a steady decrease in pine pollen and a steady increase in Cupressaceae pollen (probably incense cedar). Macrofossil analysis indicates that red fir, lodgepole pine, Sierra juniper, and mountain hemlock disappeared near the beginning of the zone, while ponderosa pine, sugar pine, and incense cedar continued. At 6500 B.P., fir pollen began increasing and charcoal decreased with the cooler and wetter conditions of the mid-Holocene.

Anderson and Smith (1994) compared the sediment stratigraphies and fossil pollen samples of nine Sierra middle-elevation meadows, from 1,857 to 2,219 m (6,093–7,280 ft) elevation and spanning latitudes from Yosemite National Park to Sequoia National Forest. Their analysis suggests that the ecological, climatic, and hydrological conditions in the Sierra Nevada changed considerably during the early Holocene interval. Pollen assemblages are dominated by plants that today grow in dry microhabitats, with lesser amounts of pollen from plants that require higher soil moisture, suggesting a more open forest structure with a less effective water cycle than today's.

The sediment stratigraphies reviewed by Anderson and Smith (1994) show a basal layer of coarse sands or gravels and a transition to colluvium or finer sands generally occurring between 10,500 and 9500 B.P. These early to middle Holocene sediments consist of silty bands of varying organic content, alternating with layers of peat, coarse sand, or gravel. The authors suggest that these deposits were generated by greater erosion rates on basin slopes than exist today, perhaps due to a much sparser vegetative cover on immature soils. The stratigraphy suggests periods of alternating meadow and forest vegetation, as in Wood's analysis of Exchequer Meadow (Wood 1979).

The initiation of wet meadow development from 4500 to 3000 B.P. is indicated by a transition from predominantly colluvium to predominantly peat in the upper zone of the cores. This transition to peaty sediment represents a widespread change in hydrologic regime within the area encompassed by these meadows. Once begun, a positive feedback cycle was generated in these locations, as increasingly organic soils promoted greater water-retaining capacity, thus providing habitats for species that require very moist soil during the hot, dry summer. Wood (1979) also recognized a change in hydrologic and depositional regime, but at later dates in the meadows he examined.

Anderson and Smith (1994) also reviewed studies of pollen stratigraphy from four high-elevation and two middle-elevation lakes, noting that the same changes to wet meadow conditions occurred at higher elevations, but 1,000–1,500 years earlier. They compare these changes with other data indicating changes in climatic and ecological characteristics of the Sierra region, such as in the tree line and elevational limits of red fir and mountain hemlock.

Davis and Moratto (1988) divided the Holocene portion of Exchequer Meadow cores into a Quercus subzone from 10,680 to 7070 B.P., a Pinus zone from 7070 to 1870 B.P., and an Abies zone from 1870 to the present. The latter division corresponds to the point of maximum fir pollen in the meadow and may indicate meadow invasion during a brief period when wet meadows dried.

Stine (1994) analyzed drowned relic tree stumps from four sites in the Sierra Nevada that indicate two periods of extended drought between about A.D. 892 and 1350. These droughts lasted at least 220 and 140 years, respectively, and were separated by a century or so of very wet conditions.

Wood (1979) analyzed seven dissected middle-elevation meadows to investigate conditions of meadow formation in the western Sierra. He concluded that depth to water table was the sole cause for determining the presence of conifer or meadow vegetation and thus inferred a generalized sequence of meadow development. However, he discusses other studies indicating that meadow development and invasion result from a complex and dynamic interaction of fire, climatic variability, long-term climatic change, and vegetative response, and his sequence does not completely conform to the more recent evidence reviewed earlier. Wood notes that "limited chronologic control suggests that scour and fill complicate this (early and middle Holocene) unit." He also asserts that all meadows identified for his study were incised since 1900, yet only seven of his twenty-three sites had established maximum ages (Wood 1979).

Anderson's (1990) analysis of the sediments of three high-elevation lakes suggests that early Holocene, high-altitude Sierra vegetation was also structurally different from that of today, with a more open forest than currently exists at these elevations. Montane chaparral shrubs, such as mountain mahogany, manzanita, and sagebrush, dominate the pollen record. Anderson suggests that the presence of these xeric species could have resulted from poor water-retention capacity of the immature soils after deglaciation, but he felt that it was more likely the result of lower precipitation than at present.

Great Basin Holocene Environment

In contrast to the Sierra Nevada, the Great Basin in the early Holocene (11,500–7500 B.P.) was evidently cooler and wetter than it is today (Grayson 1993). This change is indicated by lake levels that were considerably higher than current levels, though lower than Pleistocene maximums. Human population in the Great Basin appears to have been higher than during subsequent intervals, and archaeological evidence indicates that food was relatively plentiful. Human sites during this interval were associated almost exclusively with these more plentiful water sources (Grayson 1993).

Wigand et al. (1995) note the existence of a grassy sagebrush steppe near Eagle Lake in the northeast Sierra Nevada about 10,200 B.P. At Connley Caves in southeast Oregon, near Paulina Marsh, twenty-two of twenty-three elk specimens were dated between 11,000 and 7200 B.P. (Grayson 1993). This evidence indicates a favorable rangeland habitat during the interval. In addition, 95% of the bird remains were deposited there during this early interval, and most of those birds were tightly associated with marshy habitats, again indicating that the marsh dried up after 7200 B.P. Other evidence indicates that humans subsequently abandoned the site during the hot, dry mid-Holocene.

At Hidden Cave near Carson Sink in western Nevada, Wigand and Mehringer (1985) have shown that at about 10,000 B.P., pine and sagebrush pollen decreased somewhat, though not to levels comparable to modern spectra until 6800 B.P. Investigations in the Mojave Desert area indicate that perennial streams with marshy edges persisted until 8,000 years ago. This regime, cooler and wetter than current conditions, then disappeared, and water tables dropped some 24 m (80 ft) (Grayson 1993).

A mid-Holocene interval that was hotter and drier than today in the Great Basin is indicated by inferred vegetation, lowered lake levels, and evidence of decreased human habitation (Grayson 1993). Mid-Holocene archaeological sites are rare, with earlier lakeshore settlements abandoned. Food sources evidently became more scarce, as the appearance of seed-grinding artifacts indicates (see also "East-Side Rangeland Conditions" in the following section). Many early Holocene water sources vanished during this interval. Inferred vegetation from pollen and pack-rat midden studies indicate a shift to more xeric plants, or changes in community elevational boundaries. Jennings and Elliott-Fisk (1993) found an upward migration in the upper boundary of piñon-juniper woodlands in the White Mountains during this time.

Stine (1990) has documented that Mono Lake has had a series of at least six significant high and intervening low stands during the late Holocene. Since about 3,500 years ago, the level of the lake has fluctuated over a range of 40 m (131 ft). He argues that these fluctuations reflect decade- to century-scale climatic change during this period and may be related to observed variations in solar activity. Grayson (1993) argues that this fine-scale change probably existed in the late Pleistocene, but that it is harder to detect in older paleoenvironmental evidence lacking the finer temporal resolution of more recent sites.

The late Holocene interval in the Great Basin showed a shift to cooler and wetter conditions about 4,500 years ago, corresponding to an expansion of human population (Grayson 1993). In the northwest part of the province, increasing grasses and sagebrush began to replace the greasewood-dominated vegetation between about 5000 and 4700 B.P. In a synthesis of studies from throughout the Great Basin, Wigand et al. (1995) identify a period of maximum areal extent of juniper-dominated woodlands during the Neoglacial (4000 to 2000 B.P.). This period was followed by a 400-year drought cycle in which desert scrub communities expanded from 1900 to 1500 B.P. Greater grass abundance in the northern Great Basin sagebrush steppe between 1500 and 1200 B.P. corresponds to dramatic increases in bison remains in the archaeological sites of this region (Wigand et al. 1995). Nowak et al. (1994) and Miller and Wigand (1994) have shown that western juniper increased in this area as effective moisture increased, and retreated during times of drought. They conclude that the more extensive expansion of juniper during the last one hundred years has been affected by both increased moisture and European settlement, especially the management of livestock.

Sierra Nevada Paleoecological Rangeland Conditions

Paleoecological sources indicate that the location and extent of Sierra Nevada rangelands have varied significantly during the last 20,000 years. Modern vegetative associations are relatively recent. At lower elevations in the southern Sierra, data from pack-rat middens indicate an anomolous mix of xerophytic and mesophytic conifers from 20,000 B.P. to at least 14,000 B.P. By 12,500 B.P. the absence of the mesophytic taxa indicates a warmer and drier interval, leaving vegetation like that at upper elevations on the east side of the Sierra today.

In the central Sierra, a pattern of deglaciation and vegetative response is repeated at different times, depending on elevation. At Swamp Lake in Yosemite National Park (~1,524 m/5,000 ft), a sagebrush grassland occurred from about 16,000 to 13,700 B.P. From 13,700 to 10,400 B.P., an anomalous mix of subalpine, lower and upper montane conifers developed there. From about 10,000 to 6500 B.P., a warm, dry interval is inferred from maximum levels of oak pollen and charcoal, disappearance of several conifer species, and an open forest structure with a shrub-sagebrush understory. At 6500 B.P., fir pollen increases and charcoal decreases, indicating a shift to cooler, wetter conditions.

In middle-elevation meadows (~1,829–2,287 m/6,000–7,500 ft) of the central Sierra, deglaciation began about 13,500 B.P., with an alpine grassland existing to about 10,400 B.P. Spores of the dung fungus Sporormiella in meadow sediments indicate an abundance of Pleistocene megafauna until about 11,000 B.P. A rapid warming trend is inferred at about 10,000 B.P. From 10,000 to 6500 B.P., these locations also show an open forest structure with high oak pollen and charcoal, and a shrub-sagebrush understory. The period from 7000 to 4500 B.P. shows alternating meadow and forest soil conditions, with a decrease in oak pollen and charcoal. Wet meadow development began somewhere between 4500 and 3000 B.P., depending on location. A widespread change in hydrologic regimes is indicated for this Neoglacial interval, from about 5000 to 2000 B.P.

In the Great Basin, a cool, wet late Pleistocene is indicated by maximum lake levels, a grassy sagebrush steppe in the valleys, and subalpine conifers at low elevations. Lower lake levels indicate a warming trend from 11,500 to 7500 B.P., but with conditions still cooler and wetter than they are today. Human habitation sites first appear during this interval, with population levels higher than those at subsequent periods. A hot, dry interval from 8000 to 5500 B.P. shows lowered or vanishing lakes, abandonment of human sites associated with these lakes, and a shift to desert scrub vegetation. The period from 4000 to 2000 B.P. was also cooler and wetter in the Great Basin than current conditions, with an increase in human population, while the last 2,000 years have seen a decrease in moisture and the development of modern plant associations.

HISTORICAL CONDITIONS AND IMPACTS OF EUROPEAN SETTLEMENT

This review of Sierra Nevada rangeland ecosystems during the early years of European exploration and settlement is based on the written accounts of the explorers, trappers, settlers, naturalists, and scientists who traveled the Sierra, and their descriptions of the vegetation and the grazing animals they saw there. As noted earlier, a lack of systematic surveys of rangelands during this period makes it necessary to use these sources. Most of the accounts are of western-slope foothill conditions, although John Muir, in his extensive travels and writings and with his unique powers of observation, provides some rare and invaluable descriptions of montane and Great Basin rangeland ecosystems.

Proto-historic Rangeland Conditions (1579–1850)

Conditions of Western-Slope Foothill Grasslands

McCullough (1971) cites a number of early explorers who observed the California tule elk population before Europeans settled in the state. Typically, observers recognized that the elk was not just a large deer, but they had no other animal to compare it to, so their descriptions often used this term. Bourne (1653) published an account of the landing of Sir Francis Drake on the California coast somewhere near San Francisco in the summer of 1579, based on the notes of Drake and others on the voyage. McCullough quotes their landing party:

> The inland we found to be far different from the shoare *[sic]*, a goodly country and fruitful soil, stored with many blessings fit for the use of man: infinite was the company of a very large and fat Deer, which then we saw by thousands as we supposed in a herd.

McCullough goes on to describe the travels of Otto Von Kotzebue, the Russian sea captain who journeyed overland from San Rafael to Fort Ross in 1824. Kotzebue described the northern coast range:

> The fine, light and fertile soil we rode upon was thickly covered with rich herbage, and the luxuriant trees stood in groups as picturesque as if they had been disposed by the hand of taste. We met with numerous herds of small deer, so fearless, that they suffered us to ride fairly into the midst of them, but then indeed darted away with the swiftness of an arrow. We sometimes also, but less frequently, saw another species of stag, as large as a horse, with the branching antlers; these generally graze the hills, from whence they can see round them on all sides, and appear much more cautious than the small ones. (Thompson 1896)

McCullough (1971) estimates that the total population of tule elk in California during this period of European exploration was about 500,000 animals.

Burcham (1957) discusses the first Spanish explorers' impressions of California's range resources. He notes,

> The Spaniards entered the San Joaquin valley at least as early as 1772. . . . they noted an abundance of forage.

Jedediah Smith is believed to have been the first American explorer to cross the Sierra Nevada (Smith and Brooks 1977). Cermak and Lague (1993) describe his expedition of 1826–27. Entering the Central Valley over Cajon Pass, he skirted the western foothills of the range, crossing again from west to east in May 1827, somewhere near Ebbets Pass. Smith reported seeing oak savannas, wildflowers, and brushlands in the foothills, and a wide variety and abundance of wildlife, including elk, antelope, and wild horses.

Burcham (1957) also relates the accounts of Zenas Leonard, the cook for Joseph Walker, an early American explorer. Describing the lower reaches of the Merced River and the San Joaquin valley in 1833, Leonard observed that

> there is a level prairie on the richest soil, producing grass in abundance of the most delightful and valuable quality. (Leonard 1959)

The fur brigades undoubtedly had a significant impact on Sierra foothill ecology, through their impact on California Indian populations. The Hudson Bay Company sent expeditions to California every year from 1827 to 1843. The account of John Work, who led a Hudson Bay expedition in 1833, indicates the effect these brigades had on wildlife. His entry of February 22, referring to the Marysville Buttes area, reads:

> We have been a month here and we could not have fallen on a better place to pass a part of the dead winter season when nothing could be done in the way of trapping on account of the height of the waters. There is excellent feeding for the horses, and abundance of Animals for the people to subsist on, 395 elk, 148 deer, 17 bears, and 8 antelopes have been killed in a month which is certainly a great many more than was required. (Work and Maloney 1945)

McCullough (1971) reports the accounts of other explorers who observed the large herds of elk in the Central Valley. Wilkes (1845), reporting on federal exploration efforts of 1838–42, wrote of the American River region: "The variety of game in this country almost exceeds belief. The elk may be said to predominate." Newberry (1884), reporting on surveys to determine a route for the railroad, stated that the herds of grazing animals rivaled those of the bison of the Great Plains.

There are a number of descriptions of the Central Valley and Sierra foothills grasslands, such as Audubon's account in 1851:

> The whole country to the north and east of Stockton through to the Calaveras is most rich and splendid soil, in many places too low for farming, but the grazing was excellent, quantities of wild oats, rye grass (I think), clover and a species resembling red-top. In many places the grasses were breast high as I waded through them, but generally knee-deep. (Audubon and Audubon 1969)

From these descriptions of wild herbivore populations and their grassland habitats, it appears that the low-elevation rangelands of the project study area were very productive when the first Europeans arrived. Burcham (1957) concluded that the presettlement grasslands were composed mainly of perennial bunchgrasses, although he notes that the remains of three exotic annuals were found in the adobe bricks of the earliest missions. Burcham (1957) attributes dispersal of these species to the Spanish explorers of the 1500s.

Burcham (1957) believed that most of the conversion from perennial to exotic annual grasslands occurred in the late 1850s and early 1860s. He attributes this invasion to a variety of factors working in concert, including extended periods of drought and extremely heavy grazing pressure during this interval. However, he also notes that several early American explorers—including Leonard quoted earlier, and Audubon quoted in the previous passage—observed extensive invasion of exotic annuals in California grasslands during the middle 1800s. Thus, there was a large seed bank waiting when favorable conditions occurred.

Conditions of Montane Meadows

Descriptions of montane rangeland conditions are few, especially before 1860. Most of the accounts by early explorers seem to be focused on foothill vegetation, although it is often difficult to determine exactly where the explorers were at the time of their observations. In addition, these parties often crossed the mountains during periods of snow cover at higher elevations. It wasn't until the survey expeditions after 1860, and John Muir's accounts after 1869, that more information about rangeland conditions was provided.

Lt. John C. Fremont, U.S. Topographical Engineer, led several expeditions into California during the 1840s. Cermak and Lague (1993) discuss Fremont's crossing around Carson Pass in the winter of 1843/44. Before beginning, Fremont sent a party under Edward Kern to cross the Sierra to the south. Kern led his detachment over Walker Pass and down the South Fork of the Kern River to the location of today's Kernville in January 1844. On January 21 Kern noted,

> Among the foot-hills are beautiful groves of live and other oaks, clear from growth of underwood; the fine grass gives the country the appearance of a well-kept park.

Again, both Kern's and Fremont's crossings in January precluded any observation of rangeland ecosystems at higher elevations.

Conditions of Montane Rangelands. John Muir arrived in California in 1868, spending his first summer in Yosemite working for a sheep rancher in 1869. In this and subsequent years he would travel extensively throughout the central Sierra Nevada, always on foot, usually without a pack animal, observing and recording in detail the geologic and ecological processes he encountered. Only a few of his observations concern rangeland vegetation, but they provide some idea of what conditions were like before the severe impacts of unregulated grazing occurred.

During his travels, Muir explored the upper areas of what is now Yosemite National Park. In 1869, he encountered a bear in a meadow near his camp above Yosemite Valley. His account also describes the meadow vegetation:

> And there stood neighbor bruin within a stone's throw, *his hips covered by tall grass and flowers*, and his front feet on the trunk of a Fir that had fallen out into the meadow, which raised his head so high that he seemed to be standing erect . . . harmonizing in bulk and color and shaggy hair with the trunks of the trees and *lush vegetation*. (Muir 1982) (emphasis added)

In September 1875, Muir undertook what was perhaps the first "ecological assessment" of the giant sequoia belt of the Sierra Nevada, traveling from Yosemite Valley south to the Kern Basin, covering more than 322 km (200 mi) in his journey (Muir 1982). He described his purpose for this reconnaissance of the giant sequoia:

> In particular, I was anxious to find out whether it had ever been more widely distributed since the glacial period; what conditions . . . were affecting it; . . . and whether, as was generally supposed, the species was near extinction.

Because this trip was planned to last for some weeks during the autumn, Muir was persuaded to take "Brownie," a small wild mule, to carry provisions and two blankets. He thus had perhaps more occasion to observe and remark upon the conditions of montane meadows he encountered along the way. Muir described the general extent of these rangeland systems, as well as their individual appearance:

> Imbedded in these majestic woods are numerous meadows, around the sides of which the Big Trees press close together in beautiful lines. (Muir 1982)

Camped along the edge of a meadow in the Kaweah Basin, Muir describes its vegetation:

> There lay the grassy, flowery lawn, three-fourths of a mile long, . . . ruffled here and there with patches of ledum and scarlet vaccinium. (Muir 1982)

Later, camping two miles downstream, he related that "Brownie had plenty of grass."

One of Muir's "secret spots" was a place then known as Shadow Lake, at about 2,225 m (7,300 ft), some 13 km (8 mi) from Yosemite Valley. He described the fall conditions around the lake during his first visit in the autumn of 1872 (Muir 1982):

> The goldenrods are in bloom; but most of the color is given by the ripe grasses, Willows, and Aspens. . . . round the shores sweeps a curving ribbon of meadow, red and brown dotted with pale yellow, shading off hear *[sic]* and there into hazy purple.

After years of visiting this site without seeing anyone else there, Muir relates:

> On my last visit, . . . I was startled by a human track, which I saw at once belonged to some shepherd. . . . Returning from the glaciers shortly afterward, my worst fears were realized. A trail had been made down the mountain-side from the north, and all the gardens and

> meadows were destroyed by a horde of hoofed locusts, as if swept by fire. (Muir 1982)

Conditions of East-Side Rangelands. Fletcher (1987) describes the presettlement vegetation of Mono basin, based on historical accounts and ethnographic investigations. Perennial grasses were evidently abundant in the sagebrush-scrub community, especially giant wild rye (Elymus cinereus) and Indian ricegrass (Oryzopsis hymenoides). The Kuzedika Paiute, a small band centered in the Mono basin, collected seeds from these bunchgrasses and from desert needlegrass (Stipa speciosa) as part of their varied diet, which also included desert peach (Prunus andersonii), elderberry (Sambucus mexicana), and buffaloberry (Shepherdia argentea). In addition, the Kuzedika held rabbit drives every fall, setting fire to the sagebrush to flush out the animals, a practice that would have been favorable to grass growth.

John Muir also observed range conditions in the east-side type in 1869, when he encountered Kuzedika women in the Mono Basin, harvesting wild rye (probably Elymus cinereus) in their traditional way (Fletcher 1987):

> Four or five miles from the (Mono) lake I came to a patch of elymus, or wild rye, growing in magnificent waving clumps six or eight feet high, bearing heads six or eight inches long. The crop was ripe, and Indian women were gathering the grain in baskets by bending down large handfuls, beating out the seed, and fanning it in the wind. The grains are about five-eighths of an inch long, dark-colored and sweet. I fancy the bread made from it must be as good as wheat bread. (Muir 1911)

Vale (1975) reviewed twenty-nine journals and diaries of early travelers through the Great Basin to determine vegetative descriptions before settlement. Unfortunately, only one source indicates the type of grasses or forbs found:

> More mountainous localities . . . are covered with meadows of a tall grass resembling somewhat rye. At still more swampy points, rushes and sedge-grasses occupy the surface. Over dry, deep sandy slopes, an exceedingly nutritious grass is scattered in single bunches, bearing large sweet seeds, which are eagerly sought for by the animals and Indians. (Simpson 1876)

Unregulated Grazing of Sierra Nevada Rangelands (1850–91)

Impacts of the Livestock Industry

Burcham (1957) discusses the growth of the livestock industry in California in the 1850s in response to the tremendous surge in population after the gold rush. His data, based on U.S. Census reports, show a fivefold increase in range stock from 1850 to 1860, including about one million each of beef cattle and sheep in 1860. He notes that these data probably underestimate true livestock populations because of census sampling biases. Wagner (1989) has adjusted the census data based on U.S. Department of Agriculture (USDA) reports, and his data indicate even larger numbers: 1,800,000 beef cattle and 1,730,000 sheep in 1860. Much of this growth was due to livestock imported from other parts of the country (Burcham 1957).

Burcham (1957) describes the slackening market demand and a series of floods and droughts in the 1860s that disrupted the California livestock industry. As the gold rush boom abated, demand for beef cattle was curtailed, just as animal numbers were peaking. As demand dropped, beef cattle numbers soared to more than 3,000,000 head in 1862 (Burcham 1957). From 1863 to 1864, severe drought devastated the state's livestock industry. As large numbers of animals died of starvation, ranchers began to drive stock into the Sierra Nevada to forage. The increase in livestock numbers, combined with periodic drought and the loss of valley rangelands to farming, contributed to the impacts of grazing on Sierra Nevada rangelands from about 1870 to 1900 (Vankat 1970). Burcham (1957) believed that the most significant damage to native California perennial grasses occurred in the 1860s, although there is some evidence that the exotic annuals had made important inroads in California even before the growth of the livestock industry.

Common Property Rangeland Resources

Beesley (1996) discusses how Sierra meadows and grasslands were apparently overused before 1900. The historical accounts quoted later seem to agree that sheep grazing, as conducted during this period, affected rangeland condition more than cattle grazing. This greater impact was mainly due to the higher numbers of sheep over a longer summer season and to the sheepherders' burning practices, which were evidently more frequent and extensive than those of the Native Californians. Beesley notes that the first report by the California State Board of Forestry included recommendations to exclude sheep grazing because of the damage it caused (Wagoner 1886).

Because there was no regulation on the number of herds or the duration of their stay in the mountains, these rangelands seem to have been severely grazed on a frequent basis (Burcham 1957). Thus, there was little or no opportunity for the vegetation to recover adequately. In addition, sheepherders set fires to remove brush and invigorate the forage, again without recognizing the recovery time needed to restore lost nutrients to the ecosystem.

The irony here is that the herd management of any individual sheepherder was evidently quite reasonable, assuming each herd would not return to any grazing site for a suitable rest period. It was the combined effect of a number of herds that created the overuse. The economic incentives of sheep and wool production were evidently so great that exploitation of the "commons" was accelerated (Burcham 1957).

Under a system of common ownership of a resource, with no regulation of individual use, the so-called "tragedy of the commons" occurs. In economic terms, the common property resource, here the public rangelands, are overused, because no individual user has any incentive to conserve or steward the resource; any reduction in his use is quickly captured by other users (Howe 1979). Sierra Nevada grazing in the late 1800s is a classic example of this type of market failure, which requires collective action to remedy.

Impacts of Sheep Grazing

John Muir was one of the most ardent critics of sheep grazing as it was practiced during this period. He wrote about

> the comprehensive destruction caused by "sheepmen." Incredible numbers of sheep are driven to the mountain pastures every summer and their course is ever marked by desolation . . . , the shrubs are stripped of leaves as if devoured by locusts, and the woods are burned. (Muir 1877)

Vankat (1970) notes that a number of travelers in the Sierra during this period agreed with Muir. The California Geological Survey, headed by Josiah D. Whitney, launched a series of scientific expeditions into the Sierra Nevada, led by William H. Brewer, Whitney's principal assistant. Clarence King first worked as a field assistant to Brewer. King's description of his second visit to the Kern Plateau in September 1873 reveals the degree of change:

> The Kern Plateau, so green and lovely on my former visit in (July of) 1864, was now a gray sea . . . no longer velveted with meadows and upland grasses. . . . shepherds . . . leaving hardly a spear of grass behind them. (King 1902)

On his ascent of Mount Whitney in 1885, Magee (1885) observed:

> Mountain meadows are abundant, but the sheep-herder and his flocks have . . . worked their ruin. . . . Each of these meadows is yearly cropped several times by various flocks of sheep, and the result is that, . . . there are now only shreds and patches. The sod and the verdure are gone—eaten and trodden out; the gravel is now in the ascendant.

William Russel Dudley, professor of botany at Stanford University, traveled throughout the Sierra in the late 1890s. In 1898 Dudley, on a trip to the Kaweah Peaks region, observed that

> the great obstacle to the explorer is not the danger from crag or chasm, but the starvation threatening his animals, through the destruction of the fine natural meadow pasturage by sheep. (Dudley 1898)

On the east side, rangeland productivity decreased, evidently because of livestock mismanagement. Fletcher (1987) notes that geologist Israel Russell, who had visited Mono Lake in 1881, observed the effects of overgrazing there in 1887:

> There was formerly sufficient wild grass in many portions of the basin to support considerable numbers of cattle and sheep; but owing to overstocking, these natural pastures are now nearly ruined. (Russell 1889)

Early Public Ownership and Regulation (1891–1905)

Although federal ownership began with the creation of Yosemite, Kings Canyon, and Sequoia National Parks in 1890, Beesley (1996) points out that public ownership actually began in 1864, when the federal government granted Yosemite Valley and the central Sierra Big Trees to California to preserve and protect these areas. However, such efforts proved ineffective, and starting in 1881, the state began asking the federal government to protect Sierran lands from destructive wildfire and unregulated logging, mining, and grazing (Ewing et al. 1988).

In spite of federal ownership, however, including the establishment of the Sierra Forest Reserve in 1893, numerous problems of enforcement arose (Vankat 1970). Vankat (1970) notes that initial protection of the national parks was left to the U.S. Army, beginning in the summer of 1891, and was hampered by lack of adequate enforcement penalties. In addition, because the troops left in the fall, sheepherders would use the parks until driven out by winter weather. These problems were described by a number of officials and others who traveled through the Sierra during this period. In his 1893 report, the acting superintendent of the Sequoia National Park stated that the Kern River drainage was

> almost impassable to the traveler, to such an extent is every thing eaten off the face of the earth and trampled under foot by the hundreds of thousands of sheep which every year roam over that territory. (U.S. Department of Interior 1893)

In his 1894 report, the acting superintendent stated:

> For years the Kern River country has been a sheep range, and enormous numbers of sheep are driven there annually. As a consequence the country is entirely denuded of grasses and bushes and presents a barren, uninviting aspect. . . . the whole country has, from a beautiful land once covered with nice and luxuriant grass, been turned into a desert. (U.S. Department of Interior 1894)

Vankat (1970) concludes that the army had stopped summer sheep grazing in California's national parks by about 1896, a fact corroborated by Dudley (1896) in 1895, who observed:

> To pass from the trampled meadows of the reservation (Sierra Forest Reserve) to the protected meadows of the (Sequoia) National Park is a lesson in patriotism.

However, in 1898, while army troops were stationed in the Philippine Islands during the Spanish-American War, trespass and unauthorized use of national parks again increased, as noted by the acting superintendent in his 1899 report:

> It is estimated that at least 200,000 sheep roamed at will over the national preserve, a destructive fire raged in the Giant forest, and hunters frequented the parks with impunity. (U.S. Department of Interior 1899)

Army troops returned in the summer of 1899, but political pressure was also at work in trying to loosen the regulations, as John Muir complained in an 1899 letter:

> The sheep owners in particular are already giving trouble and promise more next season. I have just learned that . . . sheep invaded and desolated the reservation last summer under a concession made by Secretary Bliss. (Muir 1899)

After creation of the forest reserve system, the U.S. Geological Survey initiated systematic surveys of the new reserves (McKelvey and Johnston 1992). Although the primary purpose of these surveys was to assess timber reserves, they briefly noted range resources. Sudworth observed in his survey of 1900:

> There are practically no grasses or other herbaceous plants. The forest floor is clean. The writer can attest the inconvenience of this total lack of grass forage for in traveling over nearly 3,000,000 acres not a single day's feed for saddle and pack animals was secured on the open range. . . . Barrenness is, however, not an original sin. From a study of long-protected forest land in the same region and from the statements of old settlers, it is evident that formerly there was an abundance of perennial forage grasses throughout this territory. (Sudworth and Gannett 1900)

Many areas in the higher elevations appeared to recover rapidly after rest. Muir (1917) noted that in Yosemite "the gardens and beds of underbrush once devastated by sheep are blooming in all their glory." Dudley's observation about the contrast between the Sierra Reserve and the Sequoia National Park, quoted earlier, further supports the conclusion that many areas did recover rapidly, at least in terms of observable forage. However, Burcham (1957) felt that the effects of severe grazing during this time are still evident in the plant composition of these meadows.

Historical Conditions in the Sierra Nevada Rangeland Ecosystems before 1905

Historical accounts of rangeland condition and use in the late 1800s indicate that highly productive rangeland communities existed throughout the study area when Europeans arrived. Large elk herds were present on the west side of the range. Perennial grasses were dominant in the grassland communities, although exotic annuals had begun their invasion even before the arrival of the first missions in 1769.

The first extensive use of Sierra Nevada rangelands for livestock began in the 1860s. A number of observers reported severe and repeated grazing until about 1900, due in part to a lack of regulation of the common rangelands. Livestock management, combined with extended drought, contributed to the conversion of Sierra foothills to annual grasslands and is also implicated, along with climate, in the expansion of juniper woodlands on the east side of the range.

The overall agreement of many observers about the conditions and uses of rangeland vegetation tends to corroborate their observations. Without regulated access during the late 1800s, overuse of the common rangelands of the Sierra Nevada occurred, because forage conservation by any one livestock operator would be captured by another. As a result, Sierra Nevada rangelands were overgrazed, in that forage plants did not have enough time to recover after severe, repeated grazing. As unregulated grazing was eliminated, recovery of some of the rangeland vegetation in many areas was fairly rapid, at least in terms of forage production. However, questions of long-term loss of species diversity, and other potentially adverse ecological impacts, are addressed in Menke et al. 1996.

CONCLUSIONS AND IMPLICATIONS FOR MANAGEMENT

During the last 20,000 years, the location and extent of Sierra Nevada rangeland ecosystems have changed significantly in response to major changes in climatic and environmental conditions. Modern rangeland communities became established in their current locations after the end of the Pleistocene about 10,000 years ago. In the case of many riparian meadow sites, conditions alternated between meadow and forested ecosystems during the early Holocene, with modern wet meadows occurring only within the last 2,000 to 3,000 years. During the late Pleistocene a grass-sagebrush rangeland existed where montane and subalpine forests occur today, while at lower elevations where today we see chaparral and grass-woodland communities, a mixture of xerophytic and mesophytic conifers occurred.

The sagebrush grasslands of the late Pleistocene supported a diverse ecosystem of now extinct megafauna, including a large number of herbivores and a formidable group of mammalian predators. Evidence from meadow sediments indicates that these animals were abundant until about 11,000 years ago. The abundance of this diverse assemblage indicates that these rangelands were highly productive and that animal disturbance was an integral part of ecosystem health and productivity. Like the bison on the Great Plains and the diverse herbivores of East Africa, the behavior of these animals would likely have resulted in brief episodes of severe disturbance followed by longer recovery periods, as well as sequential episodes of less severe grazing on different components of the plant community by herds of different species. This disturbance regime, quite unlike traditional livestock behavior in the United States, would have provided several crucial functions for sustaining the high productivity of that rangeland ecosystem, including the breakdown and recycling of plant materials, increasing the net productivity of rangeland vegetation, improving the rangeland water cycle, and creating conditions favorable to seed germination and seedling establishment.

It is time for resource scientists to recognize that properly managed large-animal disturbance is as natural and necessary to healthy ecosystems as properly managed wildfire. Just as fire can seriously impair ecosystem health if its timing and severity are not matched to the natural rhythms of the ecosystem, so animal impacts can also be undesirable under grazing management that does not control the timing and frequency of animal disturbance. However, when fire or animal disturbance is used adaptively, where soil conditions, plant growth rates, and community dynamics are monitored and adequate ecosystem recovery times are provided, these management tools are essential to sustaining healthy Sierra Nevada ecosystems.

What role should large herbivores play in the management of Sierra Nevada rangelands today? Is it possible to achieve this former level of productivity and diversity with existing rangeland plant communities? It's clear that animal disturbance has considerable potential to effect changes in rangeland ecosystems. Whether these changes are beneficial or undesirable depends on how animals are managed. On some sites a lack of disturbance will lead to the gradual decline of ecosystem vitality, and fire or animal disturbance is needed to restore ecosystem functioning. This restoration requires livestock-management strategies that recognize beneficial plant-herbivore relationships, monitor the impacts on vegetation closely, and adjust animal behavior to achieve desired conditions.

As stated in the Introduction, a full review of the research on plant-herbivore relationships is beyond the scope of this chapter. However, it is clear that to study these relationships and their role in rangeland management properly, future research must be integrated with management and public involvement in an adaptive framework (see Kusel et al. 1996). To accomplish this kind of management on public lands, agencies will have to revise their regulations and guidelines, which focus too narrowly on forage utilization standards as an indicator of how to manage grazing animals. Rather, they need to focus on controlling the length of grazing and recovery periods based on site-specific monitoring of plant growth rates and on active management of animal behavior.

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